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Innovation in times of crisis: a pragmatic and inclusive approach to cope with urgent global sustainability challenges

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The term “polycrisis” has become a buzzword to describe the entanglement and reinforcement of multiple global crises that may put the survival of humankind at risk. It builds upon Sustainability Science and its research on the complex interactions of systemic risks. The research approach has its roots in the “Limits to Growth” report published by the Club of Rome in 1972. The publication predicted a global sustainability crisis in response to growing human resource consumption. The threat is real, but there are lessons to be learned from coping with past global crises and how they were addressed by far-sighted government initiatives that incentivized decentralized innovation systems to achieve well-defined objectives. These initiatives proved to be effective because they were based on an adequate understanding of the endogenous nature of economic development and how biocapacity and societal resilience can be enhanced through higher levels of economic complexity. Contemporary European mission-oriented innovation policies (MOIPs) with their strong faith in the state as pacesetter of the economy lack this understanding. In this paper, a more pragmatic innovation policy approach is proposed to accelerate progress on the UN Sustainable Development Goals (UN SDGs) in general, and food security in particular. It combines the target orientation of past US innovation policy missions with the commitment of international crop research networks to mobilize innovation and entrepreneurship for inclusive development. Throughout history, such opportunity-driven approaches proved to be more effective public policy responses to crisis than attempts to minimize systemic risks by limiting growth.

KEYWORDS
polycrisis, Sustainability Science, ownership problem, crop research networks, economic complexity, mission-oriented innovation policies

1 Introduction

The UN Food Systems Summit held in September 2021 in New York was launched to make food systems more productive and sustainable and catch up with all 17 Sustainable Development Goals (SDGs) by 2030 after the COVID-19 crisis. In his closing statement to the summit, UN Secretary General Antonio Guterrez called for a decade of action in view of the fragility of the world’s food systems that seem unable to fulfill the right to adequate food.[1] Yet, despite many subsequent food security and climate change summits, access to healthy and nutritious food has become more difficult for millions of people living under precarious conditions due to increasing political instability in food-exporting countries and growing inflation rates. In addition, greenhouse gas emissions generated in the food and agriculture sector continue to contribute roughly 30% of the total output of man-made global emissions (FAO, 2024). In return, climate change affects agricultural yields in many parts of the world due to increasingly unpredictable weather conditions.[2] It will require more investment in technology, innovation and capacity development to lower emissions from agriculture and, simultaneously, keep yields high and predictable in the future (Amusan and Oyewole, 2023; Tyczewska et al., 2023; Aerni et al., 2015). The Special Edition of the Sustainable Development Goals (SDG) Report published by the United Nations in July 2023 (UN, 2023) notes that progress in meeting the UN SDGs by 2030 has stalled (50% of the goals are not on track) or even gone in reverse direction (30%). The negative trend is attributed to the triple environmental crisis (climate change, biodiversity and pollution) combined with the global energy and food supply disruptions caused by Russia's invasion of Ukraine and the global cost-of-living crisis as a result of the renewed global rise of inflation. The report calls these multiple crises "polycrisis" (p. 14) and the latest UN report (UN, 2024; p. 3) describes them as "the cumulative impact of multiple environmental crises."

The most serious global crisis from a humanitarian point of view may be the global food crisis: It manifests itself in the fact that an estimated 2.4 billion people (almost 30% of the global population) experienced moderate to severe food insecurity in 2022. Figure 1 reveals a strong negative trend in low-income countries in regard to one of the most concerning indicators for long-term food insecurity and malnutrition: "Prevalence of Undernourishment" (PoU; FAO, 2024). Since 2019, the PoU has increased in these countries primarily in food insecure rural areas characterized by high-population growth rates and semi-subsistence agriculture. The other indicators to measure the targets of ending hunger (SDG Target 2.1) and all forms of malnutrition (SDG Target 2.2) point into the same direction. The region most affected by the negative trend is Sub-Saharan Africa.

The UN Report on the State of Food Security and Nutrition in the World (WHO/FAO, 2023) refrains from attributing the global food security crisis to the mutually reinforcing systemic risks associated with polycrisis. Instead, it points at the need for a better understanding of the local context pointing at the real food security challenge in most low income countries, which is rural population growth combined with lack of off-farm employment.

This explosive combination leads to land subdivision causing farm sizes to shrink to an extent that the offspring of rural households can no more subsist on these farms (Rapsomanikis, 2015; Abay et al., 2020). As a consequence, these young people become part of a population surplus in search of alternative forms of survival (Lindstrom et al., 2023). They may illegally cut forest to cultivate crops, join a paramilitary organization or migrate to nearby urban areas in search for formal employment (WHO/FAO, 2023: p. 45, 46; Negera, 2024). Since formal employment opportunities in the domestic arrival cities are very limited for resource-constrained outsiders, they often take the risk to migrate to affluent countries with the financial backing of the relatives left behind. The hope is to find well-paid work, no matter if legal or illegal (Aerni, 2016).

This crisis of the ability to make a living forces people to migrate but remains a blind spot in the contemporary literature on the global sustainability crisis. For example, the latest Global Sustainable Development Report (GSDR) report, published in 2023 with the title "Times of Crisis, Times of Change: Science for Accelerating Transformations to Sustainable Development" [Global Sustainable Development Report (GSDR), 2023], does not mention the risk of shrinking farm sizes as one of the main drivers of global migration and a major global sustainability risk. Instead, it embraces the "systemic risk" view understood as a confluence of crises caused by economic globalization that would mostly affects vulnerable populations [Global Sustainable Development Report (GSDR), 2023: p. 2]. It is very much in line with numerous contemporary appeals to overcome the "polycrisis" by embarking on a global sustainability transformation that would protect the vulnerability of nature and marginalized people. They are largely guided by the insights from the "Limits to Growth" Report' published in 1972 by the Club of Rome (Meadows et al., 1972) with its Malthusian prediction that economic growth will eventually reach its natural limits with fatal consequences for humankind. The report helped triggering the environmental movement in the 1970s, and continues to drive the alarmist contemporary discourses on climate change and the global sustainability crisis (Warlenius, 2023).

But does this narrative of proliferating crises as a result of economic growth really reflect the spirit of the UN Sustainable Development Goals (UN SDGs)? After all, the UN SDGs, passed by the UN General Assembly in 2025, are not just committed to improve people's lives and save the planet's valuable natural resources, but also to empower people by enabling inclusive economic growth (Aerni, 2021b). It is clearly embodied in the slogan of the UN SDGs "leave no one behind," which implies that the majority of the population on this planet who is still struggling to meet their basic material needs have a right to economic development.

Over the past decade, many states have embraced Mission-Oriented Innovation Policies (MOIPs) to address the "wicked challenges" associated the global sustainability crisis in the hope of enabling investment in sustainable innovation while, simultaneously, creating new jobs and prosperity (Hekkert et al., 2020). At first glance, MOIPs seem to be in line with the spirit of the UN SDGs and the emphasis on inclusive growth. Yet, the criticism of Mariana Mazzucato, one of the most prominent scholars in the field, about society's "pathological obsession with GDP" (WHO, 2022; p. 6) and her strong faith in the state as pacemaker of the economy, very much reflect the mindset of the Limits to Growth report published more than 50 years ago (Nature, 2022).

1 See the Secretary-General's Chair Summary, Statement of Action on United Nations Food Systems Summit in 2021: https://press.un.org/en/2021/sg2258.doc.htm.

2 See Joint FAO/IAEA Programme on Greenhouse Gas Reductions: https://www.iaea.org/topics/greenhouse-gas-reduction.

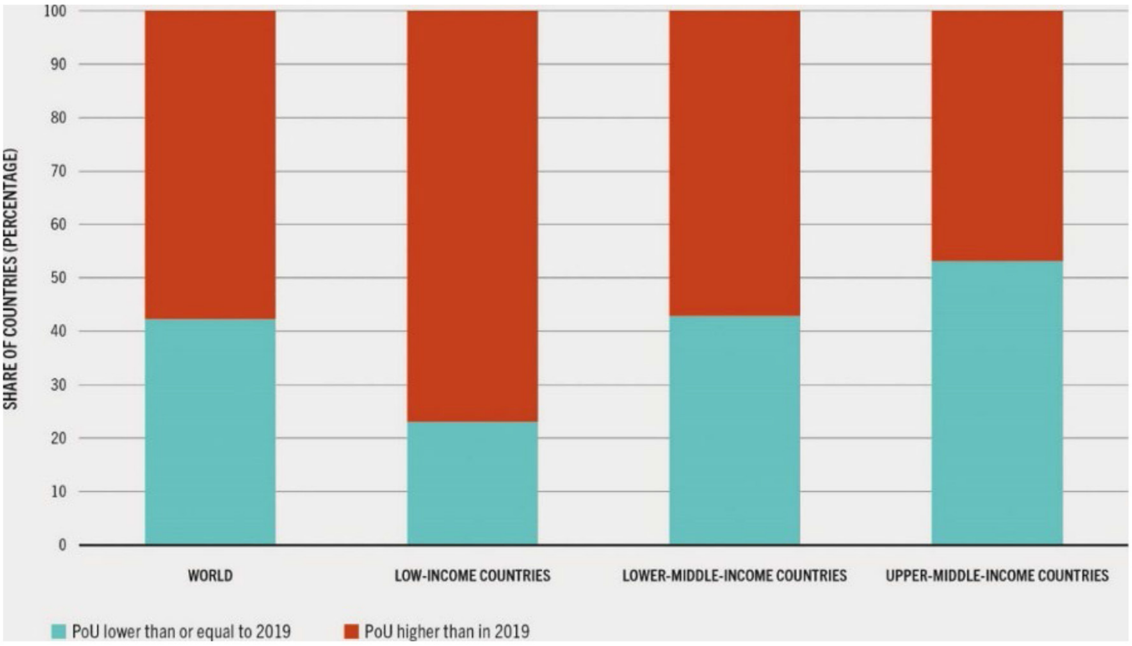

FIGURE 1
The prevalence of undernourishment (PoU; WHO/FAO, 2023). FAOSTAT: Suite of Food Security Indicators. http://www.fao.org/faostat/en/#data/FS.

The track record of such MOIPs to promote sustainable and inclusive development is at best mixed. The EU has framed its European Green Deal as a MOIP designed to make the continent climate neutral by 2050 (Mazzucato, 2018b). But current reviews of the impact of the Green Deal indicate that it may primarily lead to a shift of sustainability challenges elsewhere rather than effectively addressing them (Filipović et al., 2022; Aerni, 2023).

In this paper, it is argued that MOIPs lack a proper understanding of the role of entrepreneurship and innovation as solution-oriented drivers endogenous economic and institutional change (Adekola and Clelland, 2020; Aerni, 2018). From a historical point of view, entrepreneurship has been the driver of social mobility enabling the underprivileged to improve their material situation by seizing on economic opportunities and create economic prosperity (Jacobs, 1970; Aerni, 2015a). Achieving a certain level of prosperity is also a prerequisite to move from a short-term survival strategy to a more long-term perspective that takes into account the sustainable management of natural resources (Hollander, 2003). This may be a reason why the UN SDGs recognize the importance of empowering entrepreneurs as potential enablers of sustainable and inclusive change in many of its Goals and Targets (Aerni, 2021b).

Taking the spirit of the UN SDGs seriously would therefore require more pragmatic forms of innovation policies designed to create an enabling environment for the mobilization of technology and innovation for development (UNCTAD, 2024). Such policies include not just push-incentives in the form ex-ante state-support for R&D and subsidies for desirable economic activities but also appropriate ex-post awards to bring innovations on the market through pull-mechanisms such as an adequate protection of intellectual property rights, advanced purchasing commitments and a conducive regulatory environment that enhances the prospect of a return on investment in due time (Årdal et al., 2020). However, what matters most in the set up of favorable institutional framework conditions is a proper understanding of the nature of endogenous economic development. Policy makers need to be aware that they themselves cannot bring about desirable economic change; instead, it must come from agents within the economic system. Economic change driven by private agents may not always move in the direction that policy makers have envisioned with their national innovation initiatives. After all, it is hard to anticipate which type of innovation eventually proves to be scalable. But once innovations start to generate increasing returns, they are also likely to give birth to new markets that create prosperity while also generating positive external effects for society and the environment at large (Romer, 1994). This will be illustrated in this paper by means of far-sighted government initiatives in the 20th century designed to cope with crisis, such the Apollo Program and the Green Revolution, as well as their revival in the 21st century in response to the COVID-19 crisis. Unlike MOIPs, these initiatives focused primarily on achieving one clearly defined objective rather than trying to first achieve a societal consensus on how to achieve a global sustainability transformation that would address the "wickedness" of global crises by involving all parties involved. The focus on mobilizing all resources and competences available to achieve a joint objective may be the main reason why these previous initiatives succeeded. Yet, all of them created unintended side-effects that society had to cope with at a later stage. Such side-effects tended to be more socially accepted if the original objective was focused on a national goal such as military self-defense compared to more global objectives such as improving food security or responding to a global outbreak of virus.

It would however be misleading to attribute scalable innovations to the classic entrepreneur as the social disruptor and driver of endogenous economic change as illustrated by the economist (Schumpeter, 1934). Enabling scalable innovation in today's knowledge-based society requires know-how and knowledge that far exceeds the capacity of a firm, not to speak of a single entrepreneur. Instead, it requires collaboration across a wide network for specialized firms organized in economic ecosystems that have the ability to achieve joint technical objectives and to commercialize the resulting innovations thanks to a conducive institutional environment (Hidalgo, 2015). As such, thriving economic ecosystems contribute to a higher level of economic complexity, which, again, provides favorable conditions to effectively respond to future crises with innovation (Stojkoski et al., 2023).

Thriving economic ecosystems used to be highly concentrated in urban clusters of knowledge and know-how in high income countries that initially benefited from large-scale investments by the public sector to address a particular crisis (Jacobs, 1970; Balland et al., 2020). This also accounted for the growing economic gap to underinvested marginal regions, especially in low income countries, and led to criticism about the lack of inclusiveness of technological change (Hidalgo, 2015). However, thanks to the advent and eventual ubiquity of digital technologies, innovative economic clusters have also emerged outside major metropolitan areas. As such, they prove to be enablers of decentralized economic complexity provided that institutional framework conditions respect the subsidiarity principle in public policy and encourage investments in a robust entrepreneurial infrastructure in less urbanized areas (Liang et al., 2024; Aerni, 2021a, 2018).

Public sector support for inclusive and sustainable change through innovation should therefore learn from more pragmatic government initiative to respond to crisis through innovation. These initiatives should however be combined with the support of the self-organizing power of more marginalized but nevertheless innovative economic ecosystems to ensure more inclusiveness, and with it, more social acceptance of economic and technological change (Asheim et al., 2011; Aerni, 2018). This applies in particular to initiatives designed to promote sustainable intensification by mobilizing advances in digital technologies and biotechnology for rural development. Such initiatives in low income tropical countries must be combined with efforts to integrate farmers into formal agricultural value chains, which then enable the emergence of economic ecosystems in rural towns. They increase economic diversity and improve access to know-how, knowledge and finance and, as such, contribute to more off-farm employment, structural change in agriculture and an overall increase in farm household income (Aerni, 2015b). In this context, the case of international crop research networks is used in this paper to illustrate how international initiatives that are focused on making use of science and technology are able to address end-user priorities. They are based on solution-oriented public private partnerships designed to enable farmers to improve yields and to promote sustainable and inclusive economic change in regions that are most affected by challenges related to food insecurity and climate change (Beumer and de Roij, 2022; Aerni, 2006a). But, at the same time, such pragmatic and solution-oriented innovative crop research networks struggle to maintain the support of donors in affluent countries who make funding conditional upon the pursuit of agricultural systems that are in line with academic concepts derived from Sustainability Science. Even though they claim to be transdisciplinary, participatory and practice-oriented, they have shown little concerns for priorities in low income countries that emphasize the importance of improving agricultural productivity and enabling structural change in agriculture (Aerni, 2023).

In this context, a more pragmatic approach to innovation in times of crisis may also require a shift in the mindset of academic institutions that still tend to be guided by the spirit of the Limits to Growth Report from the 1970s in their advocacy for a societal transformation to achieve the UN SDGs (Aerni, 2021b).

2 Are we stuck in the crisis rhetoric of the 1970s?

After a period of unprecedented economic growth and prosperity in Europe and the United States following the end of World War II, concerns about its potential negative environmental and social externalities started to increase in the early 1970s and led to the first environmental movements voicing concern about the negative impact of economic growth on the environment and public health. They put pressure on governments to create environmental protection agencies and led to the first United Nations Conference on the Human Environment in Stockholm. It was launched in 1972 to address environmental concerns on a global scale (McCormick, 1991).

The sense of crisis in the 1970s was reinforced by the oil shock that led to energy shortages and created an awareness that the exploitation of natural resources to increase human wealth may have natural limits. In this context, the seminal report "Limits to Growth" published by the Club of Rome in 1972 (Meadows et al., 1972)[3] was very timely. Its dynamic macro model called "WORLD2 model" relied on the system dynamics approach in its simulations of the long-term impact of population growth and increasing affluence on life on planet earth. They predicted collapse unless humankind acts decisively to limit growth. Growth, so they proposed, can be limited by measures such as birth control and curbing investment in industrial production through regulation and the promotion of a transition toward a socially desirable and sustainable state of global equilibrium. The report describes the equilibrium state as a stabilization of population and capital, keeping the forces that increase or decrease them in a careful balance (Meadows et al., 1972, p. 171). This would require society to curb consumption in order to safeguard the rights and interests of future generations. Instead of favoring economic growth, members of such an equilibrium society would express a preference for social equality and global justice and be more focused on the greater questions that concern life on earth (Meadows et al., 1972; p. 181–82). Even though the dynamic model admitted that technological change may be able to cause some delay, it could not prevent a "tipping point" in which the system irreversibly overshoots the natural limits to growth causing the economy to spiral down toward collapse. Therefore, the report warns about technological

3 https://collections.dartmouth.edu/ebooks/meadows-limits-1972.html#epubcfi(/6/2[front_cover]!/4/1:0)

optimism as "one the most common and the most dangerous reactions" (Meadows et al., 1972; p. 154). In this context, the Green Revolution and its unintended side effects for society and the environment are illustrated as an example of the pitfalls of technological optimism (Meadows et al., 1972; p. 146–49, 164). It would fuel rather than tackle the core problem of sustainability, which is economic growth.

The report had a lasting impact on sustainability research as well as environmental, development and agricultural policies (White, 2017). It framed technological and economic change primarily as a problem rather than part of the solution when addressing global sustainability challenges. This may have brought to attention a lot of unintended side effects resulting from unrestrained technological and economic change and led to important regulatory action to curb these negative external effects resulting from growth. But it also led to a sort of mental lock-in situation in system-oriented sustainability research dividing the world in presumed "sustainable" activities associated with regulation designed to restrain consumption growth and to minimize potential risks resulting from technological change, on the one hand, and "unsustainable" activities emanating from natural resource extraction, emission-intensive growth and the adoption of potentially risky new technologies on the other hand. Yet, such a dualistic understanding of sustainability tends to discourage collaboration beyond likeminded groups and therefore is unlikely to help meet the ambitious goals associated with the UN SDGs, carbon neutrality by 2050 (Paris Accord, EU Green Deal) or, in general, the global polycrisis.

Nevertheless, the "Limits to Growth" continues to provide, consciously or unconsciously, the intellectual underpinnings of "Global Polycrisis Research", a transdisciplinary field of research concerned with the big question about the impact of humanity on planetary resources and human wellbeing (Lawrence et al., 2024).

3 Contemporary warnings about the polycrisis and looming tipping points

The term "polycrisis" became very popular in early 2022, when the abatement of the global COVID-19 pandemic coincided with the onset of the war of Russia on the Ukraine triggering a renewed global energy and food crisis (Tooze, 2021). In addition, the ongoing unresolved global environmental crises related to climate change and biodiversity loss increased the fear among policy makers of a "perfect storm" that may substantially degrade human prospect on planet earth (Lawrence et al., 2024).

Following the reasoning of the Limits to Growth report (Meadows et al., 1972), it is argued that planetary boundaries will be reached soon due the growth in scale of humanity's resource consumption and pollution output and the vast global connectivity between different human-made systems that may lead to a single macro-crisis of interconnected, runaway failures of Earth's vital natural and social systems. In order to avoid such a tipping point that will take place once humanity's prospects will degrade in irreversible ways, the scholars call for the need to create an international governance structure in support of global scientific collaboration to discern causal mechanisms that might generate a polycrisis and then design actionable policies to mitigate this risk (Homer-Dixon et al., 2022).

International reports published by the United Nations Development Programme (UNDP, 2024) and the United Nations International Children Emergency Fund (UNICEF, 2023), and the World Economic Forum (WEF; Marsh McLennan, 2023) have issued warnings that the world would spiral downwards into a self-perpetuating and compounding polycrisis. The UN Secretary General embraced this doomsday language also in his speech at the Climate Conference in in Sharm-el-Sheik (COP 27) by reminding his audience that "our planet is fast approaching tipping points that will make climate chaos irreversible." Many of his claims are derived from the recent academic literature in the field of Sustainability Science that is also widely referenced in UN Sustainability reports such as the Global Sustainable Development Report [Global Sustainable Development Report (GSDR), 2023].

3.1 Sustainability Science as a "transformative science": an analysis of the epistemic community

In 2005, the outgoing and incoming presidents of the National Academy of Sciences, Bruce Alberts and Ralph Cicerone, proposed to give "Sustainability Science" its own section in scientific journals, comparable to agricultural and health sciences. This field of research would not be defined by the academic discipline but, instead, by the complex problems it aims to address. Sustainability Science was described as being concerned with the complex dynamics that arise from interactions between human and environmental systems (Clark, 2007). It would seek to facilitate a "transition toward sustainability," improving society's capacity to use the earth in ways that simultaneously "meet the needs of a much larger but stabilizing human population while sustaining the life support systems of the planet, and substantially reduce hunger and poverty" (Clark, 2007). It was therefore also understood as a transdisciplinary and transformative science designed to enable multilevel transitions comprising systemic shifts in values and beliefs, patterns of social behavior, and multilevel governance and management regimes (Olsson et al., 2014).

In 2011, the German Advisory Council on Global Change (WGBU) then published an influential report called "World in Transition—A Social Contract for Sustainability".[4] It outlines the idea and purpose of Sustainability Science as a transformative science pointing at its overall goal to enable a great transformation toward a sustainable post-fossil-nuclear economy—comparable to the prior transformation from an agricultural to an industrial society (Polanyi, 1994). But this time the transformation should not be left to an evolutionary process but be based on a clear policy agenda informed by science and society to change production and consumption patterns as well as lifestyles. Such a transition would require a social contract in which research and education play a

4 See WGBU Flaship Report: https://www.wbgu.de/en/publications/publication/welt-im-wandel-gesellschaftsvertrag-fuer-eine-grosse-transformation.

decisive role in enabling a constructive discourse about the best ways to achieve sustainability.

The WGBU report was challenged for its problematic understanding of science (Strohschneider, 2014). After all, science primarily aims at testing research questions in a continuous process of critical self-evaluation and self-reflection (Strohschneider, 2014). The understanding of science in "Sustainability Science" is different. It frames science instead as an adaptive and problem-focused approach that requires the input of different stakeholders and rights holders to address complex sustainability problems (Ibarra et al., 2023; De Vries, 2023; Lang et al., 2012). The outcomes of this participatory process are then presented as transformation pathways to ensure that the plurality of motivations, practices, and structures is properly recognized. Sustainability Science is consequently not creating but "co-creating" knowledge in its search of academic legitimacy. Yet, the process of science usually focuses on the creation of scientifically validated knowledge, and the science community is encouraged to continuously question the resulting science-based claims and challenge the underlying baseline assumptions (paradigms), especially if an increasing gap between predicted and effective outcomes is observed (Kuhn, 1962). Sustainability Science aims instead at pluralism in methodology and epistemology to account for normativity and the inclusion of non-scientists, which is expected to promote "deep and comprehensive questioning" (Ziegler, 2011; De Vries, 2023). There is however a problem with its normative orientation; It demands a transformation in production, consumption patterns, life styles to achieve particular societal goals while disregarding the reality of social practices. These practices rely on routines and habits that build on what has been tried and tested before. They ensure that existing complex social systems are able pursue their essential functions. As such, social practices cannot be transformed merely through social manifestos and environmental activism but small adjustments need to be negotiated in view of many conflicts of interest (Nassehi, 2024; Luhmann, 1989). Sustainability Science rarely addresses these conflicts of interest despite its presumed adaptive and problem-focused approach because it may dilute its ambitious objective to bring about the transformation of society understood as moral imperative that cannot be challenged anymore by questioning claims through critical scientific research (Weingart, 2010; Strohschneider, 2014).

As such the normative nature of transdisciplinary research designed to enable a sustainability transformation implicitly tends to de-politicize the sustainability debate. This obscures the risk that consensus reached in the participatory process may well be fabricated in view of the absence of a critical science-based evaluation process (Strohschneider, 2014). After all, sustainability scholars are not impartial actors but may also have their own agenda, manifested for example in the search for recognition within their peer group or social movement. It may also induce them to disregard research results obtained outside their epistemic community (Rangan, 2000; Aerni, 2018). Scientific consensus would then primarily be maintained through a self-selection process of an epistemic community that includes scholars as well as activists who decide about the legitimacy of stakeholders in the public discourse on sustainable development (Schirone, 2024; Strohschneider, 2014).

Since the WGBU report was also endorsed by several UN agencies, the selection bias in the field of Sustainability Science manifests itself also in the Global Sustainable Development Reports (GSDR). These reports are published every 4 years to inform the UN General Assembly on the state of the SDGs [Global Sustainable Development Report (GSDR), 2019, 2023]. Its authors represent some of the leading scholars in Sustainability Science who are largely concerned with the science-policy interface that is meant to drive the transformative pathways toward sustainability. Yet, it tends to ignore that, ultimately, it is business, not science, that transforms the economy and society through scalable innovations (Hidalgo, 2015; Aerni et al., 2021). Consequently, GSDR reports never refer to the numerous UN reports or academic papers concerned with the role of entrepreneurship and innovation for sustainable development (Aerni, 2021b).

3.2 Advocacy for the post-growth transformation of agrifood systems: is it science or activism?

The tendency of sustainability scholars and activists to converge into epistemic communities that tend to discard stakeholders who may agree on the shared goals but disagree on the means to achieve them has been observed in the policy field of food security and climate change, in particular (Aerni and Zou, 2022). The UN Food Systems Summit held in 2021 involved private sector stakeholders who shared the aim of promoting sustainable and inclusive food systems, policy makers from the Global South who advocated the use of modern agricultural biotechnology as well as scientists who called for more pragmatic combinations of good agroecological practices with new technologies to better enable farmers to adapt to climate change (Aerni, 2023). Yet, scholars and activists concerned with food sovereignty and agro-ecology proved to be effective in de-legitimizing their viewpoints by opposing their presence at the Summit as alleged representatives of the dominant food and agricultural systems that would have its roots in colonialism (Friedmann and McMichael, 1989). As such they were accused of being co-responsible for the global crises that humanity currently faces such as climate change, biodiversity loss and lack of access to healthy and nutritious food (Canfield et al., 2021). The alternative to "unsustainable" industrial agriculture was outlined in an article in "Nature Sustainability" in 2022 with the title "sustainable agrifood systems for a post-growth world" (McGreevy et al., 2022). According to the authors of the paper, such food systems apply the principles of sufficiency, regeneration, distribution, commons and care through the observation of and engagement with the complex relationships between plants, soils and pollinators (McGreevy et al., 2022, p. 1014). Small-scale agroecological production systems around the world are cited as evidence of their continuing importance to household consumption, community livelihood and cultural identity as well as surrounding landscapes and ecologies. However, there is no mention that the "real utopias," as they are called in the paper, are, in most cases, generously supported by foundations and development agencies based in Western countries (Aerni, 2023). Moreover, "real utopias" largely thrive on peasant essentialism that tend to ignore the fact that small-scale subsistence farming in low income-countries is not a life-style but, in most cases, represent a harsh destiny that farmers do not wish to pass on to their offspring (Luna, 2020).

4 The endogenous nature of technological change and the fear of imbalance

Since the publication of the Limits to Growth report in 1972 the global economy has been transformed through technological change and economic globalization. The downside of it has been described in detail in the academic literature concerned with the polycrisis, sustainable transformation and de-growth. However, there is an upside to it that is hardly addressed in the sustainability debate: it is the emergence of a global knowledge economy in which firms and network of firms make effective use of new knowledge to create new products and services with an added value for customers and often also society and the environment at large. The resource "knowledge" greatly matters in efforts to manage scare natural resources more sustainably because it is non-rival in nature and therefore the only not scarce resource on this planet (Romer, 1990; Warsh, 2006; Aerni, 2007). Knowledge-based economies driven by entrepreneurship and innovation therefore have the potential to make an economic system more resilient and sustainable (Farinelli et al., 2011; Kuzma et al., 2020; Chen et al., 2022; Montiel-Hernández et al., 2024; Kahloon, 2024; Aerni, 2023; EPA, 2024). This is true in particular for the United States where annual carbon emissions have been reduced by 17 percent since 2007 (EPA, 2024), not because the government has set it as a clear target but because the concentrated knowledge and know-how in the country's innovation clusters have raised the degree of economic complexity and, with it, the ability to develop scalable solutions to environmental challenges (Kahloon, 2024). Harnessing capitalism for sustainable change therefore requires incentive mechanisms that are based on a proper understanding of the endogenous character of economic and technological change as amply described in the research field of evolutionary economics and economic complexity (Schumpeter, 1934; Jacobs, 1970; Boserup, 1981; Romer, 1990; Hidalgo, 2015).

One of the first scholars who pioneered the application of complex systems thinking to economic development, was Joseph Schumpeter. He argued from an evolutionary point of view that change over time arises from endogenous economic change—and not as a response to external stimuli. According to Schumpeter (1934), the main drivers of this change from within are entrepreneurs who may transform the economic system through their disruptive and subsequent incremental innovations in unpredictable ways and thus contribute to a technological transformation that affects all parts of the economy and society in the long run. The road to innovation is however contingent, bumpy, inefficient, wasteful and expensive because investments in R&D is based on an iterative approach that requires a lot of material and human resources, and the outcome is uncertain since most attempts to convert an idea into a commercially viable product fail (Jacobs, 1970). However, once an innovation succeeds in the market, it may not just enable the company that owns it to become highly profitable, but also contribute significantly to human welfare by generating large positive external social and environmental effects. They may manifest themselves only on the long-run when they start transforming habits and routines in a way that lowers their overall environmental footprint. That may be the reason why they are not accounted for in neoclassical welfare economics that exclusively focuses on the internalization of negative externalities (Romer, 1994). Negative externalities resulting from technological and economic change are felt in the short and medium term and can be more easily measured: they may manifest themselves in social risks such as growing socioeconomic disparities, and more unemployment in incumbent industries, environmental risk such as more emissions, pollution, habitat loss and waste and unanticipated health risk linked to the launch of novel products. These negative externalities are increasingly resented in risk-averse affluent societies. As a result, the application of the precautionary principle is frequently applied by policy makers as a risk management tool designed to take precaution in the face of scientific uncertainty. The precautionary principle has however been increasingly politicized, especially in Europe where new scientific insights that fail to validate concerns about potential risks tend to be disregarded in the face of negative public perceptions that are often shaped by parties who benefit from the status quo (Juma, 2015; Sunstein, 2005; Aerni, 2019). Therefore, disruptive technological change is unlikely to succeed unless there is public leadership creating a sense of urgency to take new technologies into consideration in view of an emerging crisis (often related to national security) that is hard to tackle with by conventional solutions only.

A lot of public resistance against new technologies that are perceived to interfere with nature in undue ways is linked to an understanding of nature as an established equilibrium that is threatened by human intervention causing volatile and harmful states of disequilibrium resulting in irreversible damage (Meadows et al., 1972; Monbiot, 2023). However, life in general and human lives in particular cannot be understood as systems in equilibrium but rather as steady states of an out-of-equilibrium system that resist the natural forces related to the laws of entropy. After all, life lasts for as long as there is energy (the sun) to maintain out-of-equilibrium systems (Nicolis and Prigogine, 1989).[5] In this context, natural as well as cultural evolution must be conceived as out-of-equilibrium systems on the move. The cultural part also involves the economy and its ability create prosperity through innovation. Commercially viable innovations require more than just an inventor. Instead they build on well-endowed human networks that contain a large amount of knowledge and know-how to process information designed to ensure the development and scale up of complex new products that embody this information (Hidalgo, 2015).

5 In other words, we as humans are subject to the laws of entropy and therefore eventually die and decompose – moving from order to chaos. But mankind as a whole is able to resist the forces of entropy by creating, using and passing on knowledge and know-how that ensures an evolving order that serves human needs.

5 The challenge of ensuring the economic viability of an innovation

The development of innovative products must attract investment in expectation of a future profit. A conditional temporary monopoly right on the commercial use of the product through intellectual property right (IPR) protection is one way to create incentives. But ultimately, the product needs to meet a demand and/or fulfill a particular function in a particular industry in order to be commercially viable. The ability of a product to meet these requirements is strongly connected to the existing order of information from which the product emerged as well as the context in which it is used. For example, the original creators of a drug may be scientists who were able to identify the human health impact of a particular bioactive trait in a certain molecule. But the knowledge of how they achieved this, is not embodied in the drug itself, which reflects the practical uses, the manufacturing and marketing of the product (Hidalgo, 2015; p. 64). The long journey from an initial scientific insight to a legally approved drug that addresses a particular human ailment is long, expensive and requires a supporting system containing a lot knowledge and know-how that needs to be renewed constantly. The cost of maintaining such an out-of-equilibrium innovation system may exceed the capacity of an entrepreneur or even an entrepreneurial firm by all means. It requires instead a target-oriented cooperation comprising a network of firms and other institutions that operate within a rule-based complex economic ecosystem that is broadly supportive of technological change, but also contains the means, knowledge and know-how to handle potential risks effectively. Such sociotechnical systems continuously evolve and better learn to handle out-of-equilibrium states embodied in the information of physical packages (instructions, recipes, protocols) that increase human capacity to cope with human-made and nature-related challenges. In this context, the economy is the system that amplifies the practical uses of the knowledge and, with it, creates not just economic but also social value thanks to a general growth in economic complexity (Hidalgo, 2015, p. 68–9).

An economic ecosystem with a high degree of economic complexity is able to mobilize and combine a high number of productive and technological capabilities and to build-up financial capital, human capital and social capital needed to continuously support, manage and improve innovation (Hidalgo, 2015). Thanks to the digital revolution a high degree of economic complexity is no more restricted to knowledge and know-how intensive urban innovation clusters. Increasingly decentralized forms of collaboration have emerged instead in many high income countries with a good entrepreneurial infrastructure outside major metropolitan areas. They led to innovative towns in rural areas that have helped to bridge the rural-urban divide (Liang et al., 2024; Aerni, 2021a).

6 The positive relation between economic complexity, sustainability and inclusive growth

A high degree of economic complexity outside large population centers tends to be strongly linked to more economic diversification and improved capacities to launch commercially viable innovations designed also for the local market. Policies that promote decentralized economic complexity may therefore result in more local ownership, more economic resilience and more local means to restore the quality of the natural environment and fight poverty (Aerni, 2021a; Artime et al., 2024).

The positive long-term trends between economic complexity and environmental quality are confirmed through various studies that tested the validity of the inverted U-shaped relationship between economic growth and environmental degradation associated with the so-called Environmental Kuznets Curve, or EKC (Lee and Olasehinde-Williams, 2024; Balsalobre-Lorente et al., 2024). The EKC predicts that environmental degradation will initially rise during the first stage of economic growth due to the scale-up effect, and then turn around in the second stage thanks to the combination effect (shift from energy-intensive manufacturing to services) as well as the technique effect (new technologies with less environmental impact). However, it may finally rise again due to the numerous forms of rebound effects (e.g., increasing efficiency leads to increasing use) as well as the obsolescence effect (shorter product-cycles producing more waste despite the promotion of a circular economy); these drawbacks may convert the U-shaped into a N-shaped EKC (Castro et al., 2022; Guo and Shahbaz, 2024).

An economy with a high degree of complexity is however in a better position to address the never-ending societal and environmental challenges resulting from economic growth through the development and effective use of non-rival ideas to develop products and processes that are better able to cope with emerging scarcities; for example by quickly offering substitutes to problematic products. The non-rivalry of ideas means that they do not degrade with increasing use but actually increase in value the more they are used. In other words, their value is proportional to the number of people who use it. Ideas drive economic life in open economies that rely on flows of goods to carry embedded ideas to ever more people (Warsh, 2006). However, rules need to evolve in response to the challenges associated with the increase in scale, for example by requiring product designs to maintain or enhance the quality and productivity of materials through subsequent life cycles where ever possible (Braungart et al., 2007). Regulation also has to ensure a certain degree of inclusiveness of technological change, ensuring that it does not increase the economic inequality gap by only benefiting the well-endowed economic ecosystems in affluent economies (Hidalgo, 2015).

Overall, an innovation-driven knowledge-based economy that is governed by well-designed rules may increase biocapacity allowing more people to have a decent living without further undermining the natural resource base. Yes, more people benefiting from the innovations also means more re-bound effects (Caldarola et al., 2023; Li et al., 2024), but it is the only way to ensure a higher degree of social and economic inclusiveness. In addition, it lowers the risk of poverty-driven environmental degradation (Juma, 2015). Therefore, making better use of knowledge, the only non-scarce resource on planet earth, and promoting decentralized economic complexity to increase the ability to respond effectively to growing scarcity problems is the only way to address the combined global environmental challenges, as outlined by UN SDGs, in an inclusive way.

7 The cost of disregarding the endogenous nature of economic change

National policies designed to achieve a higher degree of economic complexity may be risky for policy decision makers because it does not contain a compelling and simple narrative such as the "Limits to Growth" account, which starts with an account of decline but holds out the prospect of attaining an alternative economic system through careful social planning. This would then help avert the environmental crisis—provided that people embrace new values and make a joint effort to act responsibly (Meadows et al., 1972). There are many examples in history when similar convincing accounts led to real system change either on the community level or the large societal level. In this context, system change on a community level often produced promising results because the transformation was sustained by people who shared the same values and were willing to subject themselves to the same commonly defined rules of a self-sufficient community (Smith, 1998). However, system change always failed on the societal level because people in large societies have to learn to live in two worlds, the world of social exchange and the world of economic exchange, which leads to conflicting values and interests (Hayek, 1991; Heyman and Ariely, 2004; Cook et al., 2013). In most cases, social experiments designed to align private interests and values with a public vision to create a more equal and thus more sustainable society, led to growing scarcity problems. Why? Because social equality enforced by means of expropriation and redistribution of assets tends to suppress individual economic freedom, the oxygen of endogenous economic change driven by innovative entrepreneurs. Social planning may instead produce a high degree of bureaucratic complexity instead of economic complexity. This also stimulates growth, but without creating economic value, resulting in a massive misallocation of scarce resources and waste (Schumpeter, 1934; Ravallion, 2020). This is well documented with former socialist economies (Slezkine, 2017).

Yet, the "Limits to Growth" report as well as contemporary literature on the polycrisis and sustainability research do not account for the fact that some of the biggest environmental disasters and famines in the 20th century actually happened in socialist rather than capitalist economies (Wemheuer, 2014; Dikötter, 2010; Haggard and Marcus, 2007; Hill, 1992; Kupilik, 2021). Schumpeter warned about these risks and many of his predictions turned out to be accurate. However, his relevance in the discipline of economics remains marginal because his historically informed endogenous growth theory proved to be largely incompatible with the popular comparative-static baseline assumptions of general and partial equilibrium models used in neoclassical economics (Warsh, 2006). Ironically, the system dynamics approach embraced by researchers in the field of ecology has also relied on rather fictitious equilibrium models in nature neglecting the fact that out-of-equilibrium states is what drives cultural as well as natural evolution (Maris et al., 2018; Hidalgo, 2015).

The preferred comparative static models, especially in development and environmental economics continue to treat growth resulting from the adoption of disruptive new technologies as exogenously induced shocks that are primarily associated with negative externalities such as environmental risk and growing social inequality (Thanawala, 1994; Aerni, 2015a). As a consequence, a shift in emphasis in economics from growth to the distribution of income has occurred (Jones, 2015). In addition, the appreciation of the power of markets in addressing scarcity problems through innovation has decreased, while the belief, especially in development economics (Sachs et al., 2019; Fuso Nerini et al., 2024), that state bureaucracies would be well-equipped to steer the economy in a socially desirable direction has increased.

This mindset is also reflected in the recent "Berlin Declaration" signed in May 2024[6] by several well-known economists as well as political scientists who see the main cause of "decades of poorly managed globalization" in overconfidence in the self-regulation of markets and austerity, which would have hollowed out the ability of governments to respond to such crises effectively. This view seems quite outdated in view of more than a decade of quantitative easing[7] practiced by Central Banks combined with very generous government spending to finance and regulate a green transformation of the economy (Aerni, 2023).

All this does not mean that the state cannot play an important role in addressing large social and environmental challenges, but that would require to learn from history—always keeping in mind the context in which policy decisions took place.

8 Learning from the past: bold US innovation policy missions to address one single challenge

Two large US government initiatives during the Cold War, the Apollo Program to send the first man to the moon and back and the Green Revolution to promote global food security proved to be quite effective in reaching their objectives. This is also true for the global initiatives to develop, manufacture and deploy novel vaccines to manage a global pandemic caused by the COVID-19 virus in 2020. These initiatives proved that governments can indeed play a crucial role in addressing long-term as well as short-term crises while also laying the groundwork for future economic prosperity. After all the initial public investments to cope with crisis eventually gave birth to entire new industries; and the resulting increases in productivity growth, tax returns and jobs generated a large return on investment for governments and society at large.

However, the main purpose of these initiatives was never to stimulate or transform the economy but to address clearly defined technical challenges in cooperation with the private sector to provide for a public good, be it national security, food and energy security, or public health.

6 See Berlin Declaration: https://newforum.org/the-berlin-summit-declaration-winning-back-the-people/.

7 Quantitative easing is a type of monetary policy by which a nation's central bank tries to increase the liquidity in its financial system, typically by purchasing long-term government bonds from that nation's largest banks and stimulating economic growth by encouraging banks to lend or invest more freely.

It is argued that the Cold War between the United States and the Soviet Union between 1947 and 1991 was won by the United States because it was not just about proving that markets are more efficient in the allocation of scarce resources than governments, but also that governments in capitalist systems are better at creating national innovation systems designed to assume technological leadership, especially in the area of military defense, compared to their communist counterparts. In this context, the large procurement needs of the military, the National Aeronautics and Space Administration (NASA) and the National Institutes of Health (NIH) may have been more vital in the development and scale up of disruptive innovations in the fields of information technology and biotechnology than official R&D spending. Especially in the case of the Apollo Program, profits and overheads from military procurement contracts provided crucial support for company-funded R&D. This may have generated more spillovers to civil applications than the R&D projects that were directly funded by the military (Mowery, 1992).

By contrast, the Green Revolution, a Post War World II initiative designed to enhance food security in non-aligned developing countries to secure their allegiance during the Cold War was mainly based on breakthroughs in the development of new agricultural technologies, in general, and plant breeding, in particular, that were achieved prior to the Cold War (Kingsbury, 2011).

8.1 Apollo Program

Apollo Program (1961–1972) was launched by the US government in the aftermath of the success of the Soviet Union in placing the first Earth satellite, Sputnik I, into the orbit in 1957. The overall goal of the Apollo mission was not just to put the first man on the moon and return him safely to earth but also to advance US national interest in space. It was executed by NASA, a well-endowed government-funded lead-agency that achieved its objective through a large number of contracting and sub-contracting firms. These entrepreneurial firms initially worked on a contractual basis but would eventually make use of their acquired new technological capabilities to develop civil applications and commercialize them (Barbaroux and Dos Santos, 2022). The result was a huge leap in economic complexity in the numerous economic ecosystems that were involved in this very large venture (NASA, 2022; Gisler and Sornette, 2009).

8.2 The green revolution

The Green Revolution was the other prominent US public sector initiative designed to win the Cold War. It was focused primarily on generous technology transfer and capacity development programs to boost agricultural productivity in many of the newly independent developing countries that aligned with the US in the struggle against communism. The knowledge and know-how behind the development of high yielding varieties (HYV) to boost agricultural productivity existed prior to the Cold War, but its transfer, adaptation and implementation in tropical agriculture required massive support from the US government as well as the Ford and the Rockefeller Foundation (Kingsbury, 2011). US and European agro-industry also benefited indirectly from the resulting Green Revolution because it enabled them to generate large profits by selling its agricultural technologies as well as agrochemicals to ensure that the High Yield Varieties (HYVs) produced the expected high yields. The clients of the companies were however not the farmers directly but the governments in tropical countries that bought their products in bulk in order to re-sell them at subsidized prices to farmers. The downside of the deal was that capacity development for farmers who adopted the technologies was largely insufficient and, consequently, produced a lot of environmental and farmer health problems. The situation changed when farmers became the direct clients of agribusiness once governments were forced to limit their spending in response to the debt crisis in the 1980s and the subsequent structural adjustment programs (Sozzi, 2021).

Nevertheless, the Green Revolution greatly succeeded in increasing global agricultural productivity of the major food crops worldwide through the development and deployment of improved seeds, means of plant protection, irrigation and fertilizer. The resulting increase in supply led to a decrease in food prices from which virtually all consumers in the world benefited. Many farm families also benefited from research-driven productivity gains and, overall, the initiative can be called a success in regard to its primary objective, namely to improve global food security (Evenson and Gollin, 2003; Spielman and Pandya-Lorch, 2009).

Yet, the Green Revolution also generated a lot of public resistance due to perceived US political interference in domestic politics in developing countries as well as the negative side effects of agricultural intensification affecting the environment and public health (Anderson et al., 1982; Stone and Glover, 2017; Dowd-Uribe, 2023).

Overall, one could argue that the Green Revolution was never meant to solve more "wicked" problems such as addressing sustainability or global justice problems, but clearly focused on one objective: to promote food security in an effort to win over non-aligned low income countries during the Cold War period (Kingsbury, 2011). But the positive spillovers of decades-long investments in plant breeding and agricultural research and development (R&D) in the public and the private sector combined with the worldwide spread of graduate level, science-based agriculture education also contributed to a higher level of economic complexity and increased resilience in addressing domestic agricultural challenges in tropical countries that were beyond the scope of the mission of the Green Revolution (Spielman, 2003).

8.3 Why is the Apollo Program celebrated today—but not the green revolution?

Unlike in the case of the Apollo Program, where accidents and undesirable outcomes did not undermine public support for the program, the unintended side effects of the Green Revolution were already denounced by the emerging environmental movement in the 1970s as symptoms of a larger global environmental and development crisis caused by profit-oriented industrial agriculture (Meadows et al., 1972).

To date, the Apollo Program continues to be associated with national pride in US leadership in space technology, whereas the achievements of the Green Revolution and the subsequent US technological leadership in plant breeding and precision agriculture tend to be underplayed or even face outright skepticism in the international academic community concerned with sustainable agrifood systems. This may also be related to the fact that national innovation initiatives that directly respond to a perceived crisis in national security, as it was the case with the Apollo program, tend to enjoy more public support than initiatives that respond to an international crisis associated with hunger and starvation (Slovic and Västfjäll, 2010). But it is also due to the fact that the introduction of innovation in food and agriculture faced resistance from farmers and consumers throughout history (Freidberg, 2010).

The persistent narrative about the Green Revolution as a mission-oriented innovation system "gone bad" has endured over the past 50 years and was conveniently extended to more recent initiatives to make use of agricultural biotechnology to improve the quantity and quality of yields in low income countries (Kingsbury, 2011; Hielscher et al., 2016; Aerni, 2021c).

8.4 COVID-19 vaccines and the role of intellectual property rights

The outbreak of the COVID-19 pandemic in early 2020 created a global public health crisis that forced governments as well as international organizations to quickly find a coordinated response to save lives primarily by enabling the rapid development, manufacturing and distribution of effective vaccines as well as therapeutic drugs, among many other things. The mission was primarily focused on clearly defined objectives and thus comparable to the Apollo Program. Yet, the mission had to be accomplished in a very short period of time and was highly dependent on the effectiveness of coordinated action involving numerous actors in the private sector, academia, the non-for-profit sector as well as many institutions representing government and international organizations. This put governments under pressure to temporary de-regulate where ever existing regulations were not conducive to achieving the overall objectives in the pre-determined time frame. This also led to a shift of attention in the application of the precautionary principle from preventing potential unanticipated risks as a result of potential action (e.g., concerning the approval of a new technology) to enabling action to better manage life-threatening existing risks (preventing the risk of inaction). Enabling the approval of vaccines based on mRNA technology within 1 year would not have been possible otherwise (Pugh et al., 2022).

Several companies existed prior to the outbreak of the COVID-19 pandemic that made use of mRNA to find ways to induce cells in the human body to create their own medicine against diseases that are caused by a missing or defective protein (Dolgin, 2021). However, there were still unresolved challenges to drug development, which induced some companies to invest in vaccine development instead where the success rate of getting a product approved was higher. However, vaccine development is of little interest to shareholders because margins are low unless there is there a public health emergency (Laxminarayan et al., 2024). When that happened with the breakout of the COVID-19 pandemic at the beginning of 2020, the biotech companies Moderna and BioNtech, who explored already the potential of mRNA technology for vaccine development, were well positioned. Both companies proved to be able to quickly create a prototype vaccine within days after the virus's genome sequence became available online. Thanks to a powerful existing economic ecosystem concerned with vaccine testing, approval, manufacturing and deployment, two mRNA-based vaccines, in addition to a few other vaccines developed by more familiar methods, were approved by the end of the same year. But the necessary investments to make this happen in such a short time required sufficient reassurances that the future markets will eventually generate a return on investment. In this context, strong push incentives offer partial coverage of R&D costs at different development stages and support for the build-up and utilization of novel vaccine platform technologies with shorter design-to-production turnaround times.[8] In addition, pull incentives in the form of a strong protection of intellectual property rights, the optimized use of existing regulatory pathways and advanced purchasing agreements provide more certainty to investors that there is a real business case (Kalinke et al., 2022; Abbott, 2023).

There were multiple factors that delayed the development and scaling up of vaccine production, and more companies failed than succeeded in developing or delivering vaccines in a timely way. Yet, overall, the global mission to address the COVID-19 crisis was widely considered to be accomplished (Kalinke et al., 2022; Zasada et al., 2023). Access to vaccines beyond national boundaries at affordable prices was made possible to some extent by international initiatives such as COVAX[9] that provided finance for ventures including efforts to enhance access to vaccines in low and middle income countries. In addition, WHO-approved vaccines developed by the two firms that received a lot of subsidies from the Chinese government, Sinovac and Sinopharm, have also entered into manufacturing and distribution agreements with vaccine producers in numerous low- and middle income countries enabling access at affordable prices.

In case of difficulties to access IP-protected vaccines, the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization (WTO) permits member states to take drastic measures in curtailing IP ownership, such as compulsory licensing, especially when the World Health

8 Vaccine platform technologies are systems that use the same basic components as a backbone but can be adapted for use against different pathogens by inserting new genetic or protein sequences (see https://cepi.net/vaccine-technology).

9 COVAX was a multilateral effort co-led by Gavi, the Vaccine Alliance, the Coalition for Epidemic Preparedness Innovations (CEPI), the World Health Organization (WHO) and UNICEF from 2020 through 2023. It aimed at accelerating the development and manufacture of COVID-19 vaccines and to guarantee fair and equitable access for every country in the world (https://www.who.int/initiatives/act-accelerator/covax).

Organization (WHO) declares a Public Health Emergency of International Concern (PHEIC), which was the case after the COVID-19 outbreak in spring 2020.[10] However, according to the World Intellectual Property Organization (WIPO) it was not the IPR protection owned by firms involved in vaccine development and commercialization in the US, Europe and China that explained real access constraints but the challenge of organizing a network of contractors that are capable of producing novel vaccines on a large scale (Abbott, 2023; Wouters et al., 2021).

Even though COVID-19 caught the US initially unprepared, its policy response in the face of the great uncertainty was ultimately effective. It led to the mobilization of financial, scientific and developmental resources that enabled the launch of novel vaccines in record time. In addition, numerous global surveillance systems were put in place thanks to strong collaboration with the rest of the World. Collaboration also included testing for infection, monitoring for emergence of new virus variants, identification of at-risk individuals and information provided by epidemiological models that describe outbreaks in communities (Knyazev et al., 2022). Finally, temporary networks of highly adaptive companies started to develop innovative solutions to address people's needs in times of crisis (Dahlke et al., 2021). The many innovations developed to cope with the COVID-19 crisis have also rendered the World as a whole better prepared for future outbreaks. In return, just like with any other novel product offered on the market, the many disruptive as well as incremental innovations in the field of vaccine development did not happen without unintended side effects and societal resistance against novel vaccines that lacked a track record of safe prior use (Fink et al., 2022; Saadat et al., 2020).

8.5 The 'evil corporation master frame' as a driver of public resistance

The COVID-19 outbreak was framed by many protest organizations as a symptom of the environmental crisis caused by the expansion of global capitalism. They argued that human-induced ecological changes massively increased the likelihood of the transmission of dangerous communicable diseases (O'Callaghan-Gordo and Antó, 2020). Finally, the resistance movement against COVID-19 was also a manifestation of distrust against the life science industry, which was accused of privatizing profits while externalizing the social cost. Distrust against large life science companies, such as Monsanto, also proved to be one of the drivers of protest against the use of genetically modified organisms (GMOs) in agriculture (Aerni, 2021c).

The life science industry is generally associated with the slogan "putting profits before people", which is linked to the so-called "the evil corporation master frame" (Silva et al., 2023). The master frame consists of three diagnostic components: dishonesty, greed, and the contamination of authority. Applying it to vaccines and GMOs allows these resistance movements to apply a simple narrative that can be easily retold in a convincing way while stigmatizing any objecting voices as stooges of industry (Silva et al., 2023; Goffman, 1974). Even though the three diagnostic components are probably never completely absent in industry, this type of moral hazard has also been observed in government (Buchanan and Tullock, 1965), civil society (Luhmann, 1993) and academia (Bourdieu, 1984).

9 The problem with mission-oriented policies (MOIPs)

In many aspects, the public policy response to COVID-19 could be called a typical example of mission-oriented innovation policy designed to address an urgent public health challenge primarily through a technical solution (e.g., rapid development and deployment of testing-equipment, vaccines and therapeutic drugs). But many contemporary scholars who advocate MOIPs argue that it lacked an inclusive policy approach that gives more consideration to the social dimension of the challenge, for example linked to "wicked problem" of delivering health for all.[11] Wicked problems associated with global sustainability challenges are defined as complex, uncertain, and elusive, and they usually span several policy areas and academic disciplines (Nelson, 2011). Scholars of transdisciplinarity in the field of Sustainability Science aim to tackle them by first developing a common understanding of the underlying problems and then co-create options for action in a joint problem exploration (Pohl et al., 2017). The term is also used by polycrisis scholars (Undheim, 2023) who suggest new global governance structures to tackle wicked problems more effectively.

9.1 A moonshot approach to cope with "wicked" global sustainability challenges?

Advocates of MOIPs call for a "moonshot approach" in analogy to the US Apollo Program in the 1960s to overcome the wicked problems that account for the delay in achieving the UN SDGs (Fuso Nerini et al., 2024; Mazzucato, 2023; Sachs et al., 2019). They ignore however that the Apollo program consisted of one single and well-defined objective (sending the first man on the moon and back) combined with many sub-projects that were technically well-defined and delimited to achieve the overall goal. Moreover, these sub-projects could be decommissioned once the missions (in terms of technical solutions) were fulfilled. This helped to render the challenge less "wicked" and therefore better defined and easier to address—compared to a challenge such as the global sustainability crisis where there are many different parties who frame the problem differently and consequently advocate different priorities as well as means to address them (Foray et al., 2012; Nelson, 2011; Aerni, 2023).

10 The Pandemic Accord and International Health Regulations (IHR) drafted under the umbrella of the WHO focused on enhancing the capacity of low and middle income countries to adequately respond to the pandemic outbreak including facilitating transfer of technology and addressing potential constraints on "local production" that may be imposed by IP rights.

11 See final report of the WHO Council on the Economics of Health for All: https://www.who.int/publications/i/item/9789240080973.

9.2 The missing element of "urgency" in addressing sustainable development as a wicked problem

Terms such as climate change and sustainable development may suggest a sense of urgency in view of the life-threatening long-term consequences for humankind. But the element of immediate urgency that applied to the Apollo Program and, in particular, to novel vaccine development in response to the COVID-19 crisis (Reale, 2021) is largely missing. Urgency refers to the discrepancy between temporal exigencies (expectations become enduring over time through empirical validation) and substantive exigencies (expectations are to be institutionalized by aiming at a societal consensus) that may qualitatively shape the frame for policy formulation and implementation (Rottleuthner, 1989). The mission-oriented policies (MOIPs) proposed to address the grand challenges such as the UN SDGs focus on the substantive exigencies by advocating a participatory and open form of governance on all levels to reflect upon the complexity of the problem and to secure broad consensus and support for the directionality of the mission (Wiarda et al., 2023; Larrue, 2021; Mazzucato, 2021). Its advocates suppose that the time and pace that these modes of governance require overlap with the time and pace that the challenges need in order to find effective solutions that are inclusive and therefore broadly accepted. But they disregard the fact that the temporal exigencies may have to skip a lot of the substantive part in order to "get the job done". COVID-19 was a pressing global public health challenge that forced policy makers to quickly deliver results in cooperation with the actors in the private sector who had the knowledge and know-how on how to develop, produce and market novel vaccines. The focus on the technical solutions did not yet resolve the institutional question such as how to incentivize sufficient citizens to vaccinate in order to avoid free-riding, or how to make vaccines available to poor people in local income countries not just in terms of sufficient quantities but also in terms of safe delivery ensured by an adequate and effective health infrastructure (Reale, 2021). Nevertheless, getting novel vaccines developed, tested, approved, and produced in large quantities was an essential condition to address all the subsequent challenges. This aspect is often ignored by those who accuse governments for having pandered too much to the short-sighted profit motives of the pharmaceutical industry instead of pursuing the long-term goal to ensure health for all (Mazzucato, 2023). The account relies heavily on the "Evil Corporation Master Frame" (Silva et al., 2023) and ignores the fact that developing and scaling up effective solutions will only happen if there is a decent prospect for a return on investment in industry (Romer, 1994; Warsh, 2006).

9.3 Trust in the ability of government to solve problems by taming markets and curbing IP rights

Mariana Mazzucato, an influential professor in the economics of innovation and public value at University College London, pointed out in her seminal book "the entrepreneurial state" (Mazzucato, 2013) that the United States practiced a highly interventionist policy approach during the Cold War by moving public and state-funded investments in innovation and technology in a direction that did not just serve its national security interests but also contributed to future economic prosperity. This underpinned her argument that governments must not just be regarded as facilitators of the process of wealth creation in the private sector, but as the drivers of this process. This would then allow governments to foster not just the rate but also the direction of growth ensuring that economic development becomes more equitable, inclusive, resilient and sustainable (Hekkert et al., 2020).

As Chair of the recently created WHO Council on the Economics of Health for All,[12] Mazzucato criticized the global policy response to the COVID-19 pandemic because it would have followed the old-fashioned script of addressing market failure by largely focusing on de-risking private sector investment in vaccine development, manufacturing and marketing (Mazzucato, 2024). Consequently, many social equity concerns would have been ignored, especially in regard to access to novel vaccines. In this context, she deplored the fact that governments refrained from enforcing march-in rights attached to government subsidies.[13] Such march-in rights would authorize governments to require patent owners to provide licenses to "any responsible entity or entities" in case the action is necessary to protect public health or safety. The argument is based on her view that patents are mainly about the extraction of a monopoly rent based on the right to exclude others from using the IP protected innovation (Mazzucato et al., 2023).

This argument runs counter to the finding published by WIPO (Abbott, 2023) that pull-mechanisms (IPR protection, APA, Prizes) were as important as push-mechanism (government subsidies) in enabling the effective development, manufacturing and deployment of novel vaccines. Moreover, through non-exclusive licensing practices IP protected knowledge was widely shared and applied in combination with company-based undisclosed know-how to scale-up the production of vaccines. However, it is true that firms must primarily care about earning a return on investment if they want to survive on the market. Therefore, they cannot be expected to address the more complex "wicked" challenges on their own, but rather through international public-private partnerships such as COVAX and national initiatives to make domestically developed vaccines available in low and middle income countries at affordable prices (Abbott, 2023). Surely, there are examples of firms that fit the "Evil Corporation Master Frame" by refraining from joining such initiatives and instead pursue short-term profits without any sense of social responsibility (Heled et al., 2020). But they are hardly representative of the industry as a whole.

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12 See https://www.who.int/groups/who-council-on-the-economics-of-health-for-all.

13 See online commentary on the risks of using of march-in rights published by the Center for Strategic and International Studies on March 23, 2024: https://www.csis.org/analysis/use-march-rights-could-undermine-innovation-and-national-security.

9.4 A pragmatic view on IPR: the case of increasing storage capacity in electronic devices

The underestimated value of companies investing in innovations that also generate large benefits for society is well illustrated in the case of the discovery of the Giant magnetoresistance (GMR) effect for which the German biochemist Peter Grünberg received the Nobel Prize in 2007. The main application of GMR is in magnetic field sensors, which are used to read data in hard disk drives and other devices. Grünberg recognized early that the GMR effcct has the potential to massively enhance storage capacity in and promote miniaturization of electronic devices. He patented the invention in 1988. In 1996 his research center (Forschungszentrum Jülich) negotiated a deal with IBM to make use of the technology. The company paid a lump sum worth a few million Euros to obtain exclusive licensing, which some may regard as a bad deal since Grünberg's invention is embedded by now in all laptops, tablets and mobile phones all over the world. Nevertheless, the research center considered the remuneration by IBM as appropriate. Why? Firstly, there was no German company that had an interest in taking the risk of further developing the technology; secondly, IBM had to invest billions of dollars to convert the crude proof-of-concept into a commercially viable product—and there was no guarantee that it would eventually work; thirdly, electronic devices contain thousands of other patents that may be of equal relevance for the functioning of a modern electronic device; fourthly, and finally, the price of electronic devices did not increase thanks to the resulting enhanced storage capacity, so the social benefit for consumers may have been much greater compared to the profits that IBM managed to generate by increasing its market share (Dworschak, 2007). There are plenty of other examples that disqualify the simplistic view popular among advocates of MOIPs that companies would use public-sector funded research insights and quickly turn them into profit at minimal R&D expenses and at maximal social cost. It also questions the view that there is a need for governments to determine in advance which types of innovation would generate societal benefits.

9.5 Did governments create private markets?

Mazzucato follows the argumentation of the economic historian Polanyi (1994) in her assumption that government intervention eventually enabled the emergence of the profit-oriented private sector (Mazzucato, 2022). This baseline assumption has been falsified by historians (Braudel, 1982) and economists (Desai, 2003) who pointed out that the collective goods we take for granted today were initially provided through self-organizing private units in society—not the state. Eventually, the emergence of the modern administrative state, funded by taxes from private sector activities, acquired the means and competences to invest in the provision of public goods and manage them effectively in collaboration with countless contractors in the private sector. This can be well illustrated in the case of the formation of the federal state in Switzerland in the 19th century. After its creation in 1948, the Swiss government had less than 100 employees and was completely underfunded to address the emerging challenges associated with population growth, urbanization, industrialization and deforestation (Jung, 2020). Yet, in the course of the 19th century, Switzerland became a leader in the provision of public goods in the field of transport, education, public health and social assistance thanks to incentive-mechanisms that encouraged the creation public-private partnerships designed to ensure a return of investment for companies while also serving the public interest (Jung, 2020; Aerni, 2021a).

9.6 Are the private interests of government bureaucrats aligned with the public interest?

Mazzucato's confidence in the state as the trusted creator of wealth and public value is also rooted in the naïve assumption that the private interest of government officials to advance their personal career is well aligned with the public interest (Björnemalm et al., 2024). This view runs counter to the empirical insights in the well-established research field in economics called "public choice" (Tullock, 1965; Niskanen, 1971). MOIPs run by government bureaucrats may be especially prone to moral hazard because the presumed representatives of the entrepreneurial state have no real skin in the game. In other words, they do not have to pay cost associated with their failed ventures (Larsson, 2022). Recent research also shows that MOIPs tend to weaken rather than strengthen the ability of the private sector to produce scalable innovations. Why? Because they encourage companies to become "subsidy entrepreneurs" in the competition for government grants. Securing government grants may however decrease the willingness of companies to invest in risky innovation and productivity (Gustafsson et al., 2020). Nevertheless, Mazzucato praises grant-winning companies as the "willing" who are picked by governments because they are prepared to engage with a societally relevant mission (Mazzucato, 2018a).

By claiming that the private sector would only invest in innovations that address societal challenges if governments embark on a mission to create and shape corresponding markets, Mazzucato underestimates the responsiveness of innovative companies when spotting an economic opportunity resulting from a particular problem. In many cases, the offered solutions may only suit a particular customer segment but are otherwise premature because there are missing parts that still need to be developed to scale up the innovative solutions (Chung, 2004). Eventually additional features necessary to convince other users to adopt it are developed as a form of incremental innovation which then provide the necessary foundation for a future scalable innovation that can be called disruptive. Its disruptive nature then leads to the emergence of a new supporting ecosystem of institutions that provide sufficient incentives to switch from old to new ways of doing or consuming things (Hacklin et al., 2004). Yet, often the potential disruptiveness is neither recognized by government officials nor by society at large—even if the innovation would have a great potential to create positive external effects for society and the environment. This is attributed to the general inertia of institutions and acquired habits (Samadi et al., 2024)—and that is why there is a need for public leadership to overcome this inertia through pragmatic and more open-ended innovation policies that are based on a profound understanding of the endogenous nature of economic development.

10 A pragmatic innovation policy approach to address global food and environmental challenges

Pragmatic innovation policies in the past proved to be an effective response to crisis thanks to a common sense of urgency, perseverance in overcoming challenges, strong accountable institutions and a joint commitment among the relevant actors in the public and the private sector to achieve a well-defined objective that is primarily of technical nature (McGhee and Moschler, 2019). In the case of missions accomplished by the US government, this applies not just to the Apollo Program but also the development, manufacturing and deployment of novel vaccines to cope with the recent COVID-19 crisis.

The Green Revolution, backed mainly by the US government and US foundations during the Cold War, may have accomplished its main mission to increase food security in non-aligned low-income countries in Asia thanks to substantial agricultural productivity increases. In addition, it indirectly contributed substantially to a slow down of the deforestation rate in the region thanks to sustainable agricultural intensification (Stevenson et al., 2013) and the build-up of national agricultural innovation systems (Kingsbury, 2011). Yet, it also led to many environmental sustainability challenges due to the heavy use of chemical input purchased in bulk by governments in low income countries and distributed at subsidized prices to farmers. In response to these challenges, international agricultural research started to focus more on the promotion of sustainable agroecological practices and the development of innovative capacity development programs to promote the responsible use of plant protection and fertilizer (Sozzi, 2021; Kingsbury, 2011).

Environmental problems in agriculture in Sub-Saharan Africa related to soil erosion, soil nutrient deficiency and deforestation can however not be attributed to the Green Revolution because it largely failed to reach marginalized small-scale farmers there who mainly rely on low-yield rain-fed agricultural systems (Byerlee and Morris, 1993). Instead, they are the result of widespread rural poverty combined with population growth and lack of off-farm employment (Hollander, 2003; Boserup, 1965; Rapsomanikis, 2015; Abay et al., 2020).

Scholars and activists who advocate a sustainability transition of agrifood systems never refer to the environmental problems that result from rural poverty, shrinking farm sizes and lack of access to technology. Instead, they promote extensive agricultural systems as an alternative to agricultural modernization associated with the Green Revolution, which they believe has failed to deliver (Aerni, 2011). In this context, agro-ecology has become the preferred normative concept that stands for the attempt to allegedly "decolonize" agriculture, promote food sovereignty and restore an equilibrium in human-environment relationships (Shiva, 1991; Keahey, 2023).

European aid meant to address the global food and environmental crises in low-income countries has very much embraced this normative concept of agro-ecology and links it to the promotion of capacity development for agricultural innovation systems (CDAIS; Aerni, 2023). The EU-funded projects designed to promote CDAIS in tropical countries are very much inspired by advocates of Sustainability Science at European universities that are concerned with sustainable agrifood systems. CDAIS is described as following the principles of transformative science encouraging the co-creation and sharing of knowledge with local partners to create innovation niche partnerships (Schiller et al., 2023). Despite the emphasis on local inclusiveness, these projects tend to largely disregard local priorities according to the feedback of young African agripreneurs[14] (Aerni and Zou, 2022).

The United Nations Conference on Trade and Development (UNCTAD) emphasized the importance of entrepreneurship and innovation for sustainable development in numerous publications and also proposed a UN resolution on entrepreneurship for sustainable development that was passed in 2014[15] (UNCTAD, 2014, 2018, 2024). Alas, the calls have been largely disregarded in foreign aid. But disregarding the ownership principles by making funding contingent upon embracing alternative sustainable agri-food systems, as deemed appropriate by the Global North has its price in terms of aid effectiveness because it tends to crowd out bottom up-driven self-organizing local private initiatives (Sou, 2022; Aerni, 2006b). More inclusive innovation policies must therefore overcome the ownership problem in development assistance in order to become more effective in dealing with crisis related to food security and environmental degradation, which are in most cases linked to poverty rather than affluence. These policies should focus on supporting local entrepreneurs as local agents of change by connecting them to entrepreneurial ecosystems that offer access to markets, technology, capacity development, business networks and mentoring as well as access venture-capital at acceptable terms (Farinelli et al., 2011; Mason and Brown, 2014; Jacobs, 1970).

Local agents of change that focus on agricultural innovation are crucial because they have a contextual understanding of the local agricultural, economic and environmental challenges and understand well how global initiatives may or may not contribute to the mitigation of these challenges (Rangan, 2000). However, agents of change need an institutional environment and a network that supports their activities, provides them with access to capital,

14 See also comments on FSN Forum held online in November 2017 on the topic: https://openknowledge.fao.org/items/99cb650a-7c45-42b5-93ba-bf23c2438c4e.

15 The UN Resolution 69/210 on Entrepreneurship for Development was adopted by the General Assembly of the United Nations on 19 December 2014: https://undocs.org/en/A/RES/69/210 (visited on 13 October 2020). It recognizes the important contribution that entrepreneurship makes to sustainable development by creating jobs and driving economic growth and innovation, improving social conditions and addressing environmental challenges.

strengthens their skills, competences and capacities and enables them to become successful agripreneurs.

10.1 The mobilization of science and technology for development: the case of international crop research networks

International crop research networks have proved over the past three decades that they can provide an enabling platform for local agents of change committed to a business-oriented approach to food security and the sustainable management of natural resources. Many of them emerged in response to the potential of agricultural biotechnology to make crop breeding more precise, less time consuming and more tailored to local needs. But the activities of crop research networks go far beyond crop breeding. They also use advanced digital technologies to address agronomic problems at low cost to improve crop yields and reduce post-harvest losses. Directly and indirectly such technologies also contributed to economic empowerment of rural areas and capacity development through agricultural value chain integration (Aerni, 2006a; Graff and Hamdan-Livramento, 2019). In addition, research priorities in these research networks are focused on end-user needs. This "customer" orientation also requires the involvement of all the involved local parties in the approval, adaptation, adoption, cultivation, processing and commercialization of the crop. This requires a substantial amount of knowledge that is usually not found at university institutes but in product value chains. The private sector therefore plays a crucial role not just in regard to capacity development for value chain integration but in regard to:

- enabling an improved crop with locally preferred new traits to obtain regulatory approval,
- ensuring that IP licensing agreements are designed in a way that encourage sharing while preserving the interests of the IP provider
- incentivizing private sector investment in the production and dissemination of the resulting high quality seeds, preferably through joint ventures that contribute to an upgrade of the local seed sector.
- enabling farmers to solve the aggregation problem that often prevents small-scale farmers from agricultural value chain integration (Shepherd, 2018; Aerni, 2018).
- taking advantage of new digital technologies (Benni, 2023) and the trend toward platformization enabling new forms of value chain collaboration at low cost, creating new business models and contributing to the democratization of knowledge (Chiles et al., 2021; Kock, 2023).

Yet, despite the fact that transaction costs have been lowered thanks to technological change, pragmatic innovation policies are still required for the private sector to identify investment opportunities in regions with low purchasing power that have a realistic chance of a return on investment. In this context, the Orphan Drug Act (ODA) enacted in the United States in 1983 could serve as a template. The ODA had the objective to mobilize investments in the Pharma industry to develop drugs for patients suffering from rare diseases that remained unaddressed because the market was too small to merit investment. The ODA made private sector investments more attractive by means of push and pull incentives designed to enhance the expectations of a company to make a profit when investing in the development and manufacturing of new drugs for rare diseases. They include a 25% tax credit on qualified clinical trials (originally 50%), a rebate on application fees and a 7-year window of drug exclusivity. The Act proved to be quite effective in achieving the overall objective since it led to the approval of hundreds of orphan drugs for diseases and conditions that are considered rare (Miller, 2023). However, the ODA could not have possibly anticipated how modern biotechnology combined with the incentive mechanisms to invest in orphan drugs will make it highly profitable to invest in personalized medicine that caters primarily to more affluent patients (Herder, 2017). At any rate, the lessons learned from the orphan drug act could be applied in the design of an orphan crop act designed to mobilize investments into the genetic improvement of orphan crops to make them more nutritious, less dependent on petro-based chemical inputs and more resilient to climate change. Such an initiative would have to be supported by an international consortium that applies a more sophisticated combination of push and pull incentives based on lessons learned from past initiatives while ensuring that the focus remains on end-user priorities in low-income tropical countries.

Despite the absence of an Orphan Crop Act there have been successful public-private partnerships in low income tropical countries designed to build up commercially viable agricultural innovation clusters and to promote institutional change that is conducive to local entrepreneurship and innovation (Aerni, 2018). In this context, government authorities have played a crucial role as mediators that facilitate knowledge sharing and help negotiate the terms of access to technology while also offering business opportunities to foreign investors (Daly et al., 2024).

10.2 The focus of crop research networks on end-user priorities in crop breeding

A crucial advantage of entrepreneurial international crop research networks that also operate within existing agricultural innovation clusters is their focus on end-user priorities and local capacity development. They involve all local, regional and global actors that show a willingness to pursue a common goal and are open to combine knowledge from different local and global sources as long as it can be tailored to achieve local objectives. This pragmatic approach has delivered tangible results in efforts to make orphan crops more resilient, productive and nutritious (Jamnadass et al., 2020). In this context, the simplicity, versatility and cost-effectiveness of gene-editing techniques in plant breeding, in general, and the CRISPR/Cas systems, in particular, has a great potential to democratize access to precision breeding and harness the potential international crop research networks to address the challenges of climate change adaptation in tropical agriculture (Shorinola et al., 2024; Nordling, 2023).

By investing in long-term, practical and in-country trainings designed to fill specific gaps within the local context international crop research networks are also likely to stimulate endogenous economic growth if combined with efforts to create more formal seed systems managed by local agents as well as improved post-harvest management facilities that help to meet the quantity and quality criteria required for the integration into formal agricultural value chains (Gaffney et al., 2016; Rob and Cattaneo, 2021). The result of such investments would enable a shift from extremely extensive agricultural systems that also tend to result in soil degradation and deforestation to more sustainable intensification systems that keep inputs and emissions relatively low while increasing yields, improving resilience toward climate change, and protecting soil health.

Finally, the integration of farmers into formal value chains fosters the emergence of economic ecosystems that result in stronger rural-urban linkages generating new off-farm employment opportunities, new markets for farmers, a higher share of domestically run formal urban food stores, and an improvement in circular supply chain management. All this leads to a new level of economic complexity that also enhances local resilience to external shocks and generates the necessary local revenues and capacities required to better address local sustainability challenges (Knorr and Augustin, 2024; Härri et al., 2023). Many of the recent insights build on prior experience with orphan crop research networks, such as the Cassava Biotechnology Network (CBN) that proved to be successful but eventually lost support because its priorities did not align anymore with donor priorities (Aerni, 2006a).

10.3 The Cassava Biotechnology Network (CBN): inclusive innovation to improve food security

Cassava is regarded as the root crop of last resort for millions of marginal farmers and their domestic animals in tropical regions because it grows on poor soils with relatively low input and offers flexible harvesting. However, it is also considered an orphan food crop that was largely by-passed during the Green Revolution. As a result, there is a great gap between potential and realized cassava yields due to many agronomic and socioeconomic challenges that have been aggravated by the impact of climate change (Bull et al., 2011). Improving the yields and the nutritional content of cassava therefore greatly matters to global food security (Otun et al., 2023). The Cassava Biotechnology Network (CBN) was launched in 1989 at the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia to ensure that Cassava will not be by-passed once again when it comes to reap the benefits of using agricultural biotechnology in crop breeding. However, the work of CBN went far beyond crop breeding to address certain agronomic challenges. Instead, the research agenda of CBN was derived from end-user priorities and the requirements for formal value chain integration. These research priorities also reflected the preferences of local stakeholders as well as scholars from different research disciplines. Together with private sector partners CIAT promoted training opportunities on new as well as conventional breeding techniques combined with sustainable agricultural practices as well as the cost-effective handling of improved postharvest facilities. The overall objectives were to create new markets that improve the income of resource-constrained cassava producers, to render cassava a more nutritious and affordable food crop, to meet the preferred consumer taste, to make cassava a more profitable cash crop, and to lower the environmental impact of cassava cultivation (Thro et al., 1995). As such, CBN pursued a system-wide approach in addressing the challenges of Cassava agriculture ranging from improved agricultural inputs up to a higher responsiveness to consumer preferences.

As a relatively loose global network, CBN brought all actors together in triennial meetings ranging from cassava researchers in the fields of social science, agro-ecology and molecular biology to representatives of farmer organizations, consumer organizations as well as NGOs, foundations, government institutions and agribusiness. Together they determined the most urgent problems and how to address them in the most cost-effective way. This resulted in a lot of innovative solutions that made it possible for cassava to become more than just a root crop of last resort that could be excavated whenever there were local food shortages (Aerni, 2006a).

CBN also focused on enhancing the value of local knowledge through the adoption of user-friendly new technologies. For example, low-cost tissue culture laboratories were created to encourage a local network of female farmers to make better use of their local knowledge about clean cassava planting material through low-cost local tissue culture laboratories. These laboratories allowed them to clone and subsequently sell clean cassava stakes to farmers who struggle with planting material infested by viruses and affected by genetic erosion. In other words it created a new market designed to generate revenues for local people (Escobar et al., 2006).

The examples illustrate the value of combining cutting-edge knowledge and local knowledge with the purpose of jointly addressing a clearly defined local problem in a financially sustainable way. As such, the CBN approach goes beyond the mere co-creation of knowledge through participatory approaches, which tends to be treated in Sustainability Science as an end in itself rather than a means to an end.

Less than 5% of the budget of CBN went into a research project designed to create a genetically modified cassava that is resistant to the Cassava Mosaic Virus (CMV) Disease. The project was funded because conventional breeding largely failed in delivering a CMV resistant variety that was then widely adopted by cassava farmers. The main reason was that the preferred local agronomic and taste qualities were lost in the process of breeding. The use of genetic engineering had the advantage of directly inserting the virus-resistance into the locally preferred varieties. However, because of this relatively small project, all European donors eventually withdrew their funding and CBN had to be dissolved in 2006 (Aerni, 2006a). Afterwards, the Bill Gates Foundation continued to fund the part covering biotechnology research while European donors continued to fund the agro-ecological part. In this context, CBN illustrates the collateral damage created by the increasing political polarization on how to cope with the global food and environmental crisis, because those actors who should collaborate to ensure holistic solutions tend to be prevented from doing so (Aerni, 2021b).

Since CBN was dissolved in 2006, more than 51 cassava cultivars have been bred through the use of conventional and advanced breeding techniques with traits that address in most cases food security, climate change adaptation and nutritional challenges of small-scale farmers in Southern Africa in particular (Otun et al., 2023). Most of these projects were based on public private partnerships and involved a substantial amount of knowledge and technology transfer to African laboratories and farmers. In this context the Cassava Community of Practice and Partnership (CoPP) has been created as part of the NextGen Cassava Project. It played a crucial role as an enabling institution to promote inclusive development[16] and serves as a platform to disseminate and facilitate the transfer of proven tools, methods, technologies, and products (Mbanjo et al., 2021). Yet, very few of the improved crops ever reach the market. There is some consensus that this is due to lack of adequate funding and enabling policies (Tripathi et al., 2022; Mbanjo et al., 2021). The constraints are linked to a great extent to the ongoing polarized debates on sustainable agriculture. They affect approval decisions in low-income countries since they are confronted with de-facto conditionalities when seeking access to European markets and aid tied implicitly or explicitly from refraining to embrace crops that have been genetically improved by means of novel plant breeding techniques 1 (Aerni, 2023; Resnik and Swinnen, 2023).

11 Concluding remarks

The ability to respond to crisis through innovation is an essential part of what makes us human. Even in pre-historic times, hunter and gatherer communities started to innovate to increase biocapacity in response to population growth and a changing climate (Freeman et al., 2021). Later on, humans in different parts of the world prepared the ground for the neolithic revolution by transforming their food systems adopting proto-agricultural practices associated with the selection, re-growth, processing and storage of edible plants and embarking on the domestication of animals (Aerni, 2021d). This switch from extensive forms to more intensive forms of food production eventually resulted in changes in land tenure, crop-livestock systems, farm-based investment in agriculture, off-farm employment opportunities and migratory patterns. This process of endogenous development can only be explained if population growth is treated as an independent variable that induces transformational change through innovation, driven by numerous economic actors in search of new ways to earn a living (Boserup, 1965). Since these entrepreneurs are primarily focused on generating a return on their labor and capital investments they have hardly ever received recognition for having also addressed particular scarcity challenges that benefited society at large on the long run. Resentment toward profit-seeking entrepreneurs is also reflected in ancient belief systems that put trade on equal footing with theft.[17] There is however a crucial difference: whereas trade is based on the expectation that, both, the seller and the buyer, will benefit from the deal (non-zero), theft only benefits one party, namely the thief and is therefore also called a zero-sum game (Wright, 2001). The zero-sum approach used to be the rule rather than the exception in the history of population growth and agricultural development; ancient communities, which experienced population growth preferred to increase production by conquering more land in more thinly populated areas to increase the supply of servile labor, usually captives in the conquered land. Slavery-based types of agricultural systems have therefore been observed in all Western and non-Western communities with high population densities and hierarchic structures (Boserup, 1965). The decolonization of agriculture was possible only when labor-saving technologies in agriculture reduced the need for bonded labor. An issue that is hardly addressed in postcolonial studies that strongly build upon the "evil corporation master frame" (Silva et al., 2023) in their belief of the need to "decolonize" agriculture (Keahey, 2023).

Clearly, there are plenty of examples throughout history that illustrate abusive behavior in business in general and agribusiness in particular. But there is also a long history of self-regulatory responses designed to detect and punish such behavior—long before the emergence of the modern administrative state (Wang, 2011; Russell, 2005; Eichenberger et al., 2023).

Mission-oriented innovation policies (MOIPs), such as the European Green Deal, tend to disregard the self-organizing skills of complex economic systems and reveal a lack of understanding of the endogenous nature of systemic change (Hidalgo, 2015; Henrekson et al., 2022; Balland et al., 2022; Burch and Di Bella, 2021; Bilotto et al., 2023). As such, they stand in strong contrast to the pragmatic innovation policy initiatives launched by the United States in the 20th century to win the Cold War, as well as the most recent international initiative to develop novel vaccines in response to the COVID-19 pandemic. These government responses to global crises may have had their shortcomings since they narrowly focused on achieving clearly defined objectives. Clearly, the policy makers that help shaping these pragmatic innovation policy initiatives did not have the ambition to understand the complexity of "wicked" challenges associated with the "polycrisis" but realized that urgent crisis management in the face of uncertainty is primarily a process of trial and error. And this process never stops because post-crisis side effects can be as challenging as the crisis itself. Instead of planning a societal transformation designed to enable systemic change, they were eager to harness the existing knowledge and know-how within the self-organizing economic system to achieve a particular purpose through incentive systems that mobilize private sector investments for solution-oriented innovations and public-private partnerships that aim at ensuring inclusive and sustainable change. However, ensuring "inclusiveness" has been a big challenge since dynamic knowledge-based economic ecosystems are usually concentrated in urban clusters in high-income countries characterized by a high degree of economic complexity that cannot be easily replicated elsewhere. They may increase the resilience of the host country toward external shocks, but they are not designed to address the global food security crisis, global environmental challenges, such as climate change and communicable diseases, a public health challenge that affects first of all low-income countries with a low degree of economic complexity.

This fact is well-illustrated in regard to the Prevalence of Undernourishment (PoU), one of the most important indicators to

16 See https://www.nextgencassava.org/.

17 For example, in Roman religion, Mercury (Hermes in Greek Religion) was the god of shopkeepers and merchants, travelers and transporters of goods, as well as thieves and tricksters (see https://www.britannica.com/topic/Mercury-Roman-god).

assess progress of UN SDG 2 on reducing hunger and malnutrition. It indicates that, since 2019, food insecurity in Sub-Saharan Africa has increased, despite substantial funding from high-income countries to promote sustainable agriculture in this region. This may be due to the failure of donors to promote ownership-driven development through a more comprehensive support of local entrepreneurship and innovation (Aerni, 2023). This would not just include a more effective use of digital technologies to better connect towns in rural areas to formal urban markets but also more pragmatic and holistic approaches to promote sustainable and productive agriculture by combining agro-ecological practices with modern plant breeding techniques, such as gene-editing. The advantage of gene-editing is that traits to improve productivity and resilience can be directly activated in the locally preferred crops. Overall, these new technologies have become more user-friendly and affordable, as illustrated in this paper, and therefore can be more easily combined with existing local knowledge and practices. This creates new opportunities for local entrepreneurs to stimulate endogenous growth provided that they are able to operate in an institutional environment that supports economic change and the integration of local business into formal value chains.

This opportunity-driven approach is crucial in building up innovative local ecosystems that enable regions to reach a higher level of economic complexity that enhances the local ability to create prosperity and local jobs and to effectively address local problems through target-oriented collective action. Such a development would be very much in line with the overall purpose of the UN SDGs, which is "to leave no one behind."

The risk-focused transdisciplinary approach advocated by Sustainability Science, has little to show in terms of tangible outcomes despite its claim to be practice- and solution-oriented. The problem with this field of research is that it has embraced the risk-averse baseline assumptions of the Limits to Growth Report published more than 50 years ago. Its implicit framing of economic and technological change as the main threat to global sustainability neglects the fact that it may actually become part of the solution, if accompanied by more pragmatic and target-oriented innovation policies. This has been illustrated in this paper using the case of international crop research networks in general and the Cassava Biotechnology Network (CBN) in particular. Such networks have not just focused on rendering orphan crops in low income tropical countries more productive, climate resilient and nutritious but also mobilized effective public-private partnerships designed to create added-value products derived from these crops to improve farm household incomes and create more off-farm employment. The success of such value added products depends however on the ability of farm households to meet the strict formal requirements to get integrated in value chains that cater to urban consumers elsewhere. Successful value chain integration results in a massive upgrade of local know-how and knowledge that also accelerates the transformation of local agrifood-systems and structural change in rural areas. This may eventually lead to more outside investment designed to further diversify the local economy. In this context, an institutional setting that increases the likelihood of innovators and investors to earn a decent return on investment for their risky ventures constitutes an essential precondition for the emergence of innovation-driven local economic ecosystems that apply knowledge for development (Kock, 2023; Juma and Yee-Cheong, 2005).

Considering all these aspects, a pragmatic innovation policy approach that is based on learning from prior experience combined with the institutional support for self-organizing bottom-up initiatives in low-income countries may be the most effective response to crisis. It may also contribute to a more people-centered and inclusive approach to achieving the UN Sustainable Development Goals by 2030.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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